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QUATERNARY GEOLOGY OF THE GANDER (NTS 2D/15) MAP AREA

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ABSTRACT

The Gander area of central Newfoundland has been affected by at least two ice-flow events. The first was eastward, from a source to the west of Mount Peyton; it formed striae and dispersed sediment eastward. In particular, clasts from the Mount Peyton intrusive suite are common across the study area. The second sediment-moving phase of ice flowed north to north-northeastward from a source in the Middle Ridge area, as shown by striations overprinting those of the last flow, by clast provenance and clast fabric data.

Diamictons are the most common sediment type found. They have a sandy matrix, containing 30 to 60 percent clasts, are moderately compact, and are massive, although small moderately to well-sorted sand and granule gravel lenses are common, especially beneath clasts. This sediment was probably deposited by basal melt-out processes. A veneer of clast-rich diamicton is common, and probably represents supraglacial meltout till. Valleys are commonly filled with glaciofluvial outwash sediments, up to 60 m higher than present river levels in the Southwest Gander River valley. These were deposited during deglaciation, and have been partially reworked into modern alluvial and deltaic deposits. In the area of The Outflow, laminated silt and clay sediments indicate a proglacial lake or marine incursion that extended up to 40 m above the present level of Gander Lake. Modern Gander Lake, to the east, may have been filled by ice at this time, effectively blocking the inferred major pre-glacial drainage system at the eastern end of the lake, routing drainage into the modern Gander River valley. Postglacial sediments include colluvial deposits at the base of steeper slopes, and bog deposits, which are common in poorly drained areas.

Subglacial meltout till is a suitable sampling media for drift exploration. Supraglacial meltout till, glaciofluvial and colluvial sediments, if sampled, should be considered separately because of their differing transport and depositional histories. Most sediments have a sandy matrix and are, therefore, permeable. Care should be taken when placing waste-disposal sites within these sediments to avoid potential groundwater or surface water contamination. Zoning of aggregate deposits identified within the area should also be implemented to allow their extraction.

INTRODUCTION

Knowledge of the Quaternary geology of any area is crucial in the development of projects in the surficial environment. These could include siting of waste-disposal sites, groundwater studies, building and highway construction, municipal zoning for residential and commercial development, or in exploration for mineral or granular resources. The Gander map area (NTS 2D/15), as well as hosting several communities, has been the site of mineral exploration over the last 50 years or more. Although bedrock is well exposed over part of the area, much of it has a thick glacial sediment cover, which has impeded exploration. This is especially the case south of Gander Lake, where generally, bedrock exposure is limited to stream beds.

The objective of this project is to map the distribution of surficial sediments and features and describe their characteristics, map ice-flow directional indicators, and determine a glacial history for the area that will explain these observations. This will not only aid mineral-exploration activities by providing data on directions and possibly distances of transport of glacial sediment, but will also be a tool to be used by other projects influenced by surficial sediment.

LOCATION AND ACCESS

The Gander map area (NTS 2D/15) is located in central Newfoundland, between 48°45' and 49°00' north latitude, and 54°30' and 55°00' west longitude (Figure 1). It contains the communities of Gander and Glenwood, both north of Gander Lake, but is otherwise uninhabited apart from a few scattered cabins. Access to most of the field area was reasonable. The area north of Gander Lake is accessible by using the Trans-Canada Highway, and the road network around Gander. The southwest part of the area is accessible by all-terrain vehicles via a logging road south of Glenwood. The Rodney Pond area was reached by all-terrain vehicle via the Mint Brook road from Gambo. The shoreline of Gander Lake and some winter roads were accessible by boat. Other areas, especially north of Rodney Pond, and between Hunt's Ponds and Rodney Pond, were not examined because they are only efficiently accessed by helicopter.

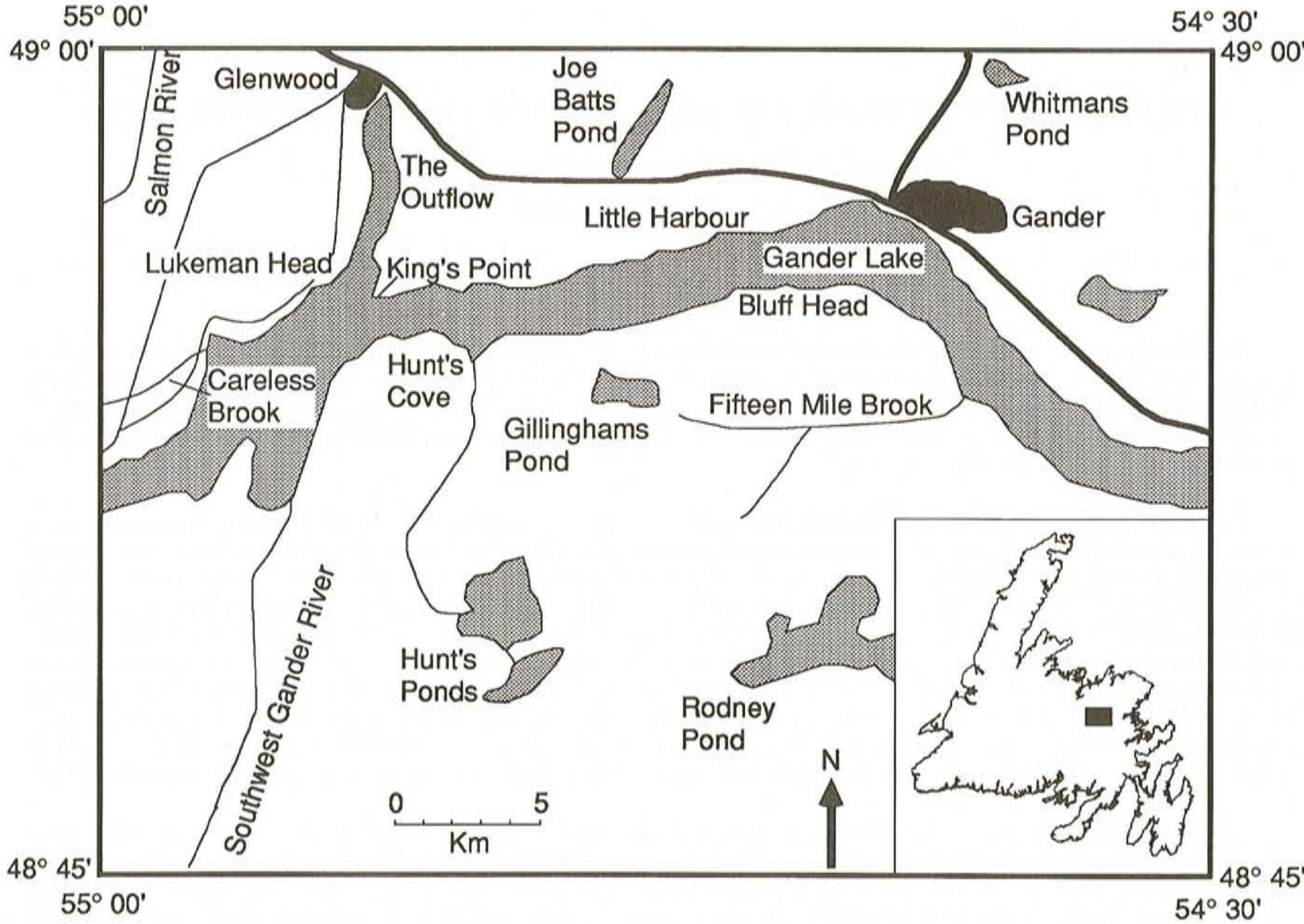

Figure 1. *Location map and places referred to in text.*

BEDROCK GEOLOGY

The study area straddles the boundary between the Gander and Dunnage tectonostratigraphic zones (Williams *et al.*, 1974; Figure 2). The Gander Zone constitutes the eastern part of the area and consists of a north-northeast-trending belt of Ordovician quartz-rich sandstones, siltstones, pelites, semipelites, psammites and volcanic rocks of the Gander Group (Blackwood, 1982). The Dunnage Zone to the west is composed of Middle Ordovician quartz-poor sandstone, shale, siltstone and conglomerate rocks of the Davidsville and Botwood groups, which are non-conformable over the Gander Group. The boundary between the two zones is faulted and has been previously known as the GRUB (Gander River Ultrabasic Belt), although the replacement term of Gander River complex has been proposed by O'Neill and Blackwood (1989). Rocks of the Gander River complex are composed mainly of pyroxenite, which has been locally serpentinized, but also include local exposures of carbonate, talc, and gabbro. These rocks are exposed over a width of 3 km north of Gander Lake, but only in restricted areas between Gander Lake and Hunt's Ponds to the south.

Both the Gander and Dunnage zones are intruded by a number of Devonian-age granitic plutons (Figure 2). The granitic plutons exposed in the area have distinctive characteristics. To the west, granite of the Mount Peyton intrusive suite is a fine- to medium-grained, equigranular, pink to red-weathering granite (Blackwood, 1982); gabbro intrusions are commonly associated with this unit. The Middle Ridge granite in the south is generally a medium- to coarse-grained, muscovite–biotite, white to pale-pink-weathering granite. A granite in the Gillinghams Pond area is similar in character, except that biotite rarely occurs (O'Neill, 1990). Small plutons of this unnamed granite occur to the west and northwest of Rodney Pond. The western part of the area is underlain by the Gander Lake granite, which contains potassium feldspar megacrysts in a biotite, quartz and feldspar matrix (O'Neill, 1990).

Historically, the main focus of mineral exploration in the area has been the ultramafic and associated rocks of the Gander River complex. Numerous asbestos, chromite and base-metal showings have been identified (Newfoundland Department of Mines and Energy, 1984), following initial work by the Newfoundland and Labrador Corporation Limited (NALCO) in the 1950's (Blackwood, 1982). More recently, exploration activity has centred on gold and stibnite occurrences within sediments of the Davidsville Group.

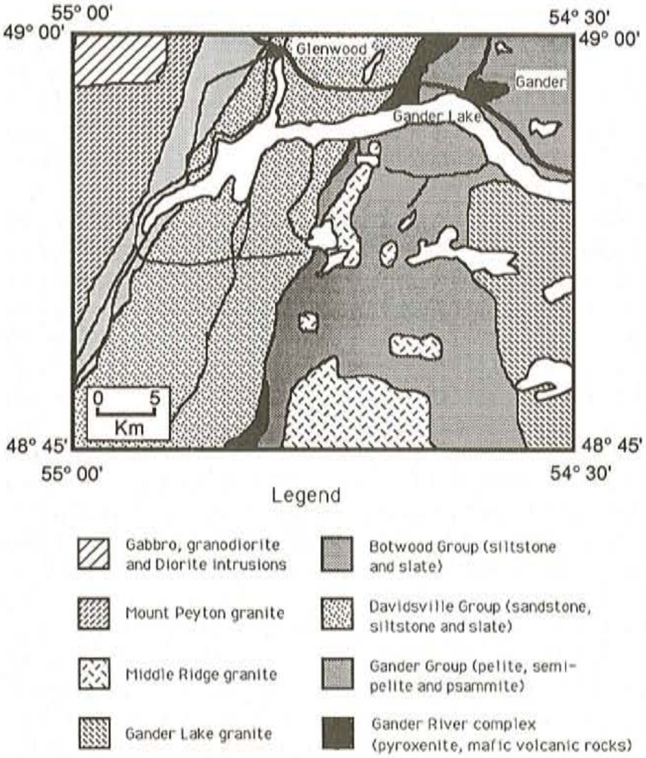

Figure 2. *Bedrock geology map of the Gander Lake area.*

O'Neill (1990) has postulated that the Gander Group sediments and the aureoles around the granitic intrusions may host precious metals.

PREVIOUS WORK

The Gander area straddles the 'inner' and 'outer drift zones' of Jenness (1960). The boundary between the two is marked by a discontinuous, boulder-till moraine, although it is obscured in the Gander area by heavy vegetation cover (Jenness, 1960). Jenness (1960) suggests that this zonation evolved as a result of rapid ice-retreat from its terminal positions on the northeast coast to a major stillstand position marked by the moraine. The outer drift zone is characterized by thin ground moraine of local origin and glaciofluvial sediments in valleys flowing out from the inner drift-zone area. Subsequent climatic amelioration led to final retreat of inland ice, much of which stagnated. The inner drift-zone area is characterized by thick, locally derived ground moraine, having a hummocky or ribbed surface topography. Jenness's (1960) description has largely been unchallenged since its publication. Lundqvist (1965) recorded several striations in the area, and Vanderveer and Taylor (1987), St. Croix and Taylor (1990) and Taylor and St. Croix (1989) described ice-flow patterns as showing an early eastward and a later north to northeastward flow.

FIELD PROGRAM

Bedrock outcrops were examined for striae or other ice-flow indicators and 113 striation sites were recorded. Detailed descriptions of surficial sediment were made from road, stream or lake exposures and included sedimentary structures, texture, and clast rock type. In areas with poor exposure, 15 pits were dug using a skidder-mounted backhoe, although these were largely confined to the northern part of the field area. In other areas of poor exposure, hand-dug testpits that penetrated to the soil C-horizon were examined. In 38 exposures of diamicton that extended into the C-horizon, clast fabrics of 25 elongate pebbles were measured. Results were plotted on a stereogram and analyzed using the Stereo™ software package for the Apple Macintosh-computer (MacEachran, 1990). Principal eigenvalues, which measure the strength of a fabric, and K values, which measure the modality of the fabric distribution, were produced using the methods outlined by Woodcock (1977). Normalized eigenvalues (S1) can range between 0.33 (random) and 1.0 (unidirectional). K values of less than 1 suggest girdle distributions. Matrix samples were taken from 103 sites for textural and geochemical analysis. Matrix samples (< 2 mm/-1ϕ) were sieved through a nest of 6 stainless-steel sieves (4ϕ to -1ϕ), and the silt/clay fraction ($< 4\ \phi$) was analyzed for grain-size distribution using a Coulter Counter, Model TAII-L (100 and 200 μm apertures). One-hundred and two samples of between 50 and 100 clasts each were also taken and rock types identified.

ICE FLOW

The glacial erosional evidence (mostly striae) suggests at least two major ice flows affected the area (Figure 3). The first was generally eastward (100 $\pm$ 20°) and is found across the whole area. In sites where two flows are encountered, the east flow is always preserved in the lee of, or crosscut by, a later ice flow that is generally north-northeastward (020 $\pm$ 20°). The poor striation preservation potential on the metasediments that surround the Gander Lake shore means little striae data was derived from this area. The early flow parallels the lake in its central part and some valley-parallel striae are found in the southeast oriented part of the lake. Ice-contact gravels and esker ridges identified in the Butts Pond area (Vanderveer *et al.*, 1987) at the eastern end of the lake suggest ice flowed through this area and into the sea.

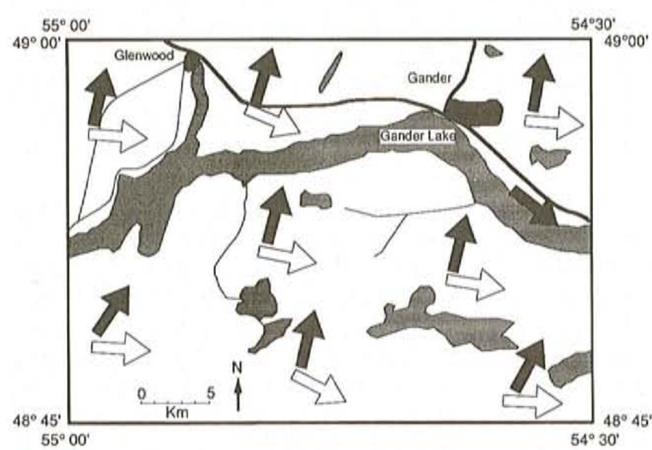

Figure 3. *Simplified ice-flow direction map. The open arrows refer to the oldest recorded phase of movement; the black arrows refer to the most recent flow.*

The later flow roughly parallels the Southwest Gander River valley and The Outflow in the west, but obliquely crosses Gander Lake in the east.

Similar ice-flow directions to those described above have been reported from the southwest of the study area on the Northwest Gander River map area (NTS 2D/11) by Proudfoot *et al.* (1988), and by St. Croix and Taylor (1990) to the west. A postulated southward flow across the Gander Lake area from a source in the Long Range Mountains (see St. Croix and Taylor, 1990), which was based on southeastward-directed striae on the north coast, was only substantiated at one site, to the north of Gander Lake. Well-oriented clast fabrics (i.e., $S1 \leq 0.7$ and $K \geq 1.0$) that may be indicative of ice-flow directions (Harrison, 1957; Lawson, 1981; Dowdeswell and Sharp, 1986; Woodcock, 1977) are generally consistent with the erosional data. Most have a roughly north–south orientation ($350 \pm 30°$), although several show trends perpendicular to last ice flow (see Batterson *et al.*, 1991 for more detail). These may either represent preservation of the earlier ice-flow event or transverse fabrics from the later flow.

CLAST PROVENANCE

It was anticipated that the diverse bedrock geology of the Gander area would make clast-provenance studies an effective method of determining paleo ice-flow directions, and distances of glacial transport. This method has been effective in other glaciated areas (e.g., Batterson, 1989), but its applicability is constrained by a number of factors including the physical characteristics of the rock type, which affect transport potential, correct rock-type identification and accurate bedrock mapping.

The resistance to comminution of a rock type during glacial transport is dependent on its hardness, grain size, and structure (e.g., a hard, massive granite clast will be transported farther than a well-bedded shale clast, which will be comminuted to finer grain sizes over a shorter distance) (Shilts, 1982). A small clast may not be representative of the rock type from which it has been derived, resulting in the mis-classification of a rock type (e.g., a diabase may be confused with a gabbro if fine grained enough, and individual components of a coarse-grained conglomerate may not be recognized as such). Similarly, structural features such as foliation may not be recognizable from clast fractions. Thus, it may be difficult to relate clasts to specific bedrock units.

In the Gander area, granites from three plutonic units are distinguished on the basis of colour, texture and mineralogy (Blackwood, 1982; O'Neill, 1990). Similarly, ultrabasic and associated volcanic rocks of the Gander River complex are restricted to a thin north-northeast- to south-southwest-trending belt through the central part of the area. Conglomerates are widely distributed throughout the Davidsville Group to the west, but have not been identified in the Gander Group within the field area or along expected ice-flow lines. These three groups of rocks were, therefore, considered useful indicators of glacial transport directions and distances.

Diamictons contain clasts that are primarily derived from the underlying bedrock. Exceptions are conglomerate clasts of the Davidsville Group found at a site 3 km west of Gander, underlain by Gander Group rocks. Clasts of the Gander River complex were also identified in the Whitmans Pond area, and to the northwest and southwest of, as well as in, Gander. Granites from the Mount Peyton intrusive suite are widely dispersed across the area. In samples from the area of The Outflow, 15 km east of the nearest outcrop, Mount Peyton granites account for up to 20 percent of clasts. They are also common in the interfluve between the Northwest and Southwest Gander rivers to the south of Gander Lake. In glaciofluvial sediments in the Careless Brook and Salmon River areas, Mount Peyton granites form up to 90 percent of clasts. These granites were found as far east as Gander, 28 km from the nearest source. Murray (1882) also notes the eastward transport of Mount Peyton granites and identifies them at the eastern outlet of Gander Lake. Muscovite-rich granites from the Middle Ridge and Gillinghams Pond areas are common south of Gander Lake, and were identified at several locations to the north of the lake, but consistent with transport directions described earlier. South of Rodney Pond, a cluster of 6 sites, 4 km south of the pond show up to 40 percent granite clasts, with the nearest granite source mapped 5 km to the south. The clasts are pink, fine- to medium-grained granites and not the medium to coarse leucogranites mapped to the south. Although these clasts could represent transport in excess of 5 km, their concentration suggests that it is more likely that they have a more local source from a previously unmapped granite intrusion. O'Neill (personal communication, 1990) located one previously unrecognized granite outcrop on the southern margin of the map sheet, which may be part of this suggested intrusion. Along the logging road south of Rodney Pond, granite clasts in diamicton are fine to medium grained, in contrast to the published megacrystic leucogranite description (O'Neill, 1990). The area is heavily drift covered and the bedrock was mapped on the basis of few outcrops. It is likely, therefore, that finer grained phases of the Gander Lake granite exist, and these form the source for the clasts identified in the Rodney Pond area.

In summary, diamictons in the area are largely composed of locally derived material. However, they contain a component of far-travelled sediment. Mount Peyton granites have been identified 25 km east of the nearest source and granites from the Middle Ridge–Gillinghams Pond area have been found at least 18 km north of their nearest source. These distributions are consistent with the ice-flow history derived from striae, and suggest that sediment deposited during the early eastward flow event has been reworked by later, northward-flowing ice.

PHYSIOGRAPHY AND GEOMORPHOLOGY

The Gander map area can be divided into four geomorphological zones:

1) North of the Gander Lake basin, the contact between the Gander River complex and Gander Group is marked by increasing elevations, from 150 m a.s.l.

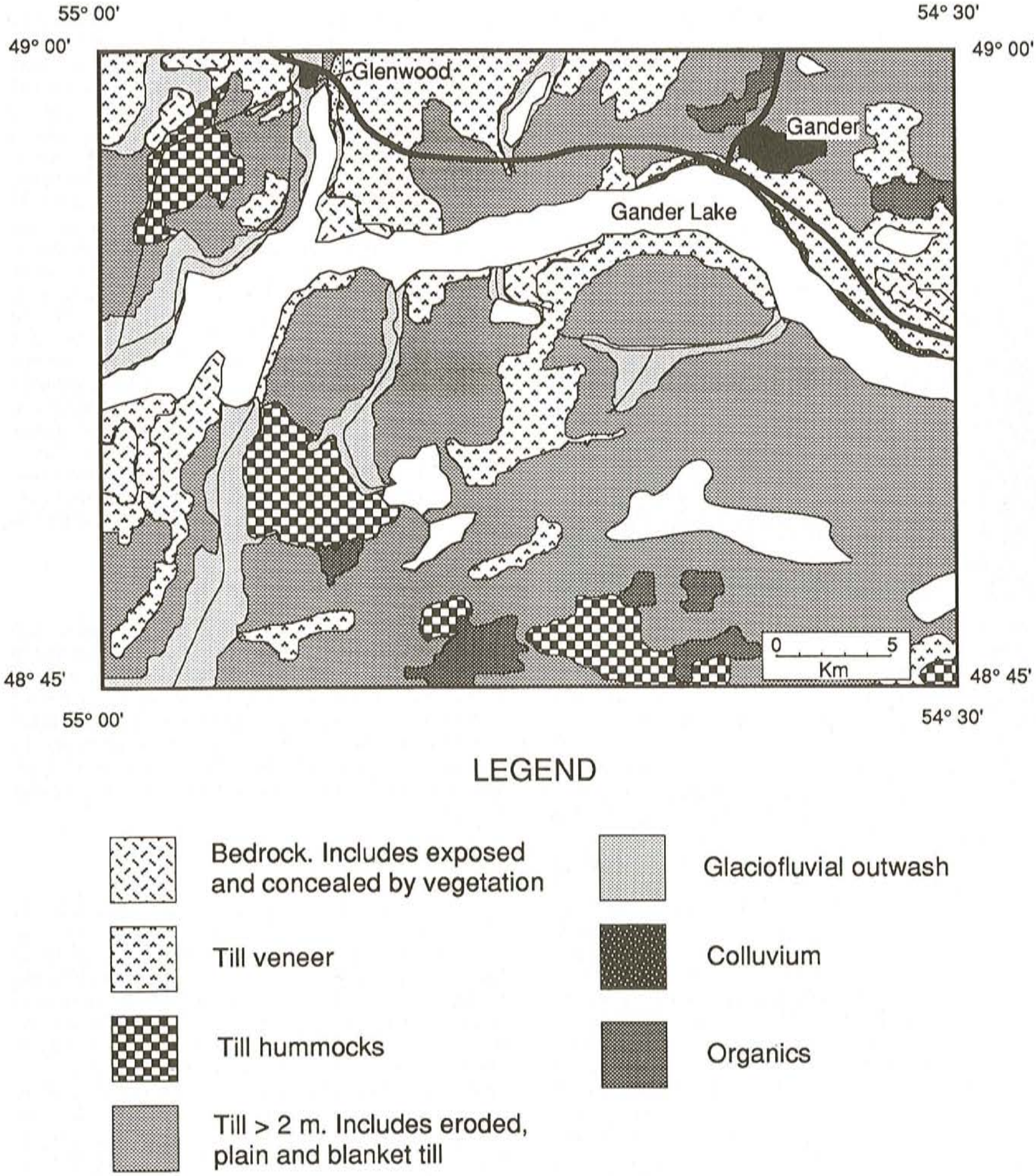

Figure 4. *Simplified surficial geology map.*

in the east to less than 110 m a.s.l. in the west. Topography underlain by Gander Group rocks is flat and featureless, compared to the irregular topography to the west. Surficial sediment is generally thin (Figure 4), having numerous bedrock exposures, especially along the Trans-Canada Highway. An exception is an area of till ridges oriented transverse to flow that occur in the Whitmans Pond area, north of Gander (Figure 1).

2) South of the Gander Lake basin, the area is dominated by hilly topography, with elevations up to 250 m a.s.l. Hillsides are commonly incised by small meltwater channels 5 to 10 m wide and 2 to 3 m deep. Streams drain the lowlands between hills, the larger streams being Hunts Brook and Fifteen Mile Brook. Surficial sediments are thicker and have rare bedrock outcrops. Till hummocks are common, especially in the bog-covered lowlands south of Rodney Pond and around Hunt's Ponds (Plate 1).

Plate 1. *Coarse grained muscovite leucogranite boulders exposed on hummocks north of Gillinghams Pond. The underlying bedrock is Gander Group sediments. A thin surface cover of boulders is common across the study area and probably represents a supraglacial sediment.*

3) The west of the study area is dominated by glaciofluvial and alluvial sediments. The Southwest Gander River valley is about 6 km wide in the map area, with a flat, up to 1.5-km-wide, valley floor. The valley contains eroded and terraced outwash up to an elevation of about 98 m a.s.l., or 60 m above present river levels. Some sediment has been reworked by the present channel into an alluvial plain up to 1 km wide. Extensive outwash sediments occur in the Careless Brook valley, where terraces up to 40 m high were observed. Meltwater outflow from the Southwest Gander and Careless Brook valleys and from the Northwest Gander River valley (southwest of map area) apparently flowed northward through The Outflow into the modern Gander River valley. A veneer of outwash sands and gravels overlying diamicton is common in this area and beach sediments up to 39 m above Gander Lake have been identified. Outwash sediments also fill the Hunt's Brook valley coming out of Hunt's Ponds and entering Gander Lake at Hunt's Cove.

4) The dominant feature on the Gander map area is Gander Lake. The lake is 47 km long, an average of 1.9 km wide, has a surface area of 11,500 ha (Yoxall, 1981), and a surface elevation of 25 m a.s.l. Although the bathymetry of the lake is unknown, Jenness (1960) reports soundings in the Fifteen Mile Brook area at a maximum of 274 m, or 249 m below present sea level. Murray (1882) reports sounding depths of 123 m off King's Point, decreasing to 93 m in the Northwest Brook Cove and 27 m at the extreme eastern end of the lake. Jenness (1960) suggests that the lake is a fiord of glacial origin, being aligned with known paleo ice-flow directions, with an outlet to the sea through a presently outwash-filled valley to the east. To the south of the lake, hills rise to about 213 m a.s.l., giving a maximum relief of at least 487 m for the trough. The Gander Lake basin contains little evidence of glaciofluvial or fluvial activity to the east of King's Point. The lake shore is dominated by bedrock, and valley sides are mostly composed of a till veneer or bedrock having a thin vegetation cover. Exceptions are thicker colluvial sediment on the north shore of the lake in the Gander area and extensive areas of glacial sediment found to the east of Fifteen Mile Brook. The hillside in this area is composed of diamicton, dissected by numerous closely spaced meltwater channels. Two small eskers were also identified on the aerial photographs in this area.

QUATERNARY SEDIMENTS

Sedimentological analysis centred on diamictons because these are the sediments most used in mineral-exploration studies in drift-covered areas. Detailed descriptions are made from north of Gander Lake; south of the lake, where thicker drift is found, there were very few natural exposures and the use of the backhoe was limited due to time constraints. In this area, only inferences about sediment characteristics can be made. Other major sediment types in the area are also described.

DIAMICTONS

The major sediment type in the area is a reddish-brown to grey, sandy diamicton. Reddish-brown diamictons are generally confined to the west of the area, the colour likely being derived from the red sediments of the Botwood Group (Blackwood, 1982). In the areas underlain by Gander Group sediments, diamictons are generally grey. Diamictons throughout the map area have a similar sand-dominated matrix (Figure 5). The lack of variation is likely due to the consistency of bedrock, which forms the bulk of the matrix. Field estimates of the clast content of diamictons vary between 30 and 75 percent, having an average of about 50 percent. Clast to clast contacts are common in the coarser grained diamictons. Occasionally, fragile clasts (e.g., well-bedded, soft, shale) were found within the diamicton. Although grain-size distributions have not been completed on these samples, diamictons in the area appear to be poorly sorted.

Diamictons are commonly slightly to highly compacted, the degree of compaction being increasingly proportional to the fines content. Clasts are pebble to cobble sized, with boulders accounting for less than 10 percent of clasts by

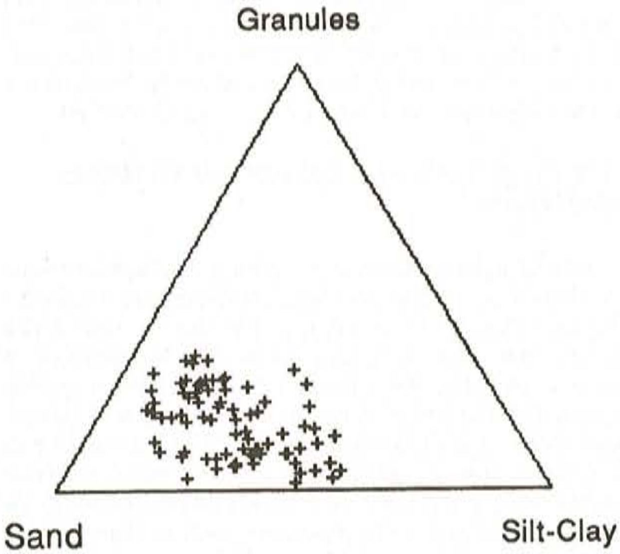

Figure 5. *Ternary plot of diamictons from the Gander map sheet area.*

volume. Generally, clasts are sub-angular to sub-rounded, the degree of roundness mainly being related to the rock type. Granite clasts are commonly sub-rounded because of their hardness and texture. Metasediments are generally sub-angular. Similarly, preservation of abrasion features on clasts is related to rock type. Fine-grained, hard, rock types (e.g., siltstones, rhyolites) are commonly striated in diamictons in the Gander area. Coarser grained, softer rock types (e.g., metasediments) rarely preserve striations. The upper surface of clasts commonly have a thin (< 0.2 mm) silt to fine sand coating that is difficult to remove by washing. Clast fabrics are variable. Strong fabrics (i.e., those with an S1 > 0.6 and K > 1.0) show clast orientations generally consistent with the last phase of ice movement (Batterson *et al.*, 1990).

In small exposures, or where moist, the diamictons appear massive. However, in larger exposures, particularly those which have been exposed for some time, sedimentary structures were found. Beneath cobbles and boulders, a thin (2 to 5 grains thick) layer of sand or granule gravel is common, and rarely, oval lenses of moderately sorted sand and granule gravel were noted. Sub-horizontal to horizontal fissility is common.

The characteristics of diamictons outlined above are generally consistent with a subglacial melt-out till origin (Dowdeswell and Sharp, 1986; Dreimanis, 1988; Lawson, 1981; Shaw, 1982). The striated clasts, their sub-rounded form and well-oriented clast fabrics is indicative of basal transport. The presence of sorted layers beneath clasts and throughout diamicton units suggests the presence of water during deposition, and the presence of fragile clasts indicates a passive depositional process. In melt-out tills, the clast fabric is inherited from the glacial transport process (Dreimanis, 1988) and is, therefore, commonly parallel to ice movement. However, Lawson (1981) notes the susceptibility of melt-out tills to resedimentation during and following deposition, which weakens clast fabrics. This could explain the variability of clast fabric noted in diamictons in this area that otherwise appear similar.

Complex stratigraphy in diamicton units is rarely exposed in the Gander area. In the Little Harbour area, west of Gander, 2 gravel pits reveal a complex stratigraphy. In the westernmost pit, located about 2 km northwest of Little Harbour, there is a 5 m exposure comprising 4 sediment units (Figure 6). The lowest unit (Unit 1) is a 2.5- to 3.0-m-thick, brownish, diamicton. It has a fine to medium sand matrix, with less than 10 percent silt-clay content. Clasts form about 60 percent of the unit are mostly pebble to boulder, angular to sub-angular, and of local provenance. Fine-grained clasts are commonly striated. Two clast fabrics were taken and provide well-oriented but girdle distributions (S1=0.72, K=0.58; S1=0.62, K=0.44). The diamicton is poorly compacted and contains numerous sub-horizontal, irregularly shaped lenses of massive coarse sand and granule gravel. Lenses are common beneath clasts.

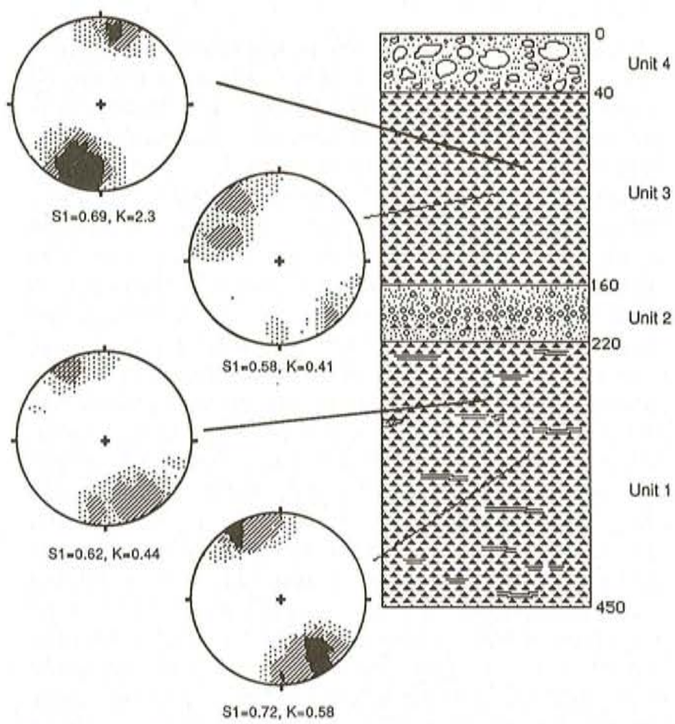

Figure 6. *Stratigraphic column and clast fabrics from a gravel pit in the Little Harbour area. Not drawn to scale. Refer to text for description of units.*

Overlying a sharp, undulating contact, Unit 2 is about 80 to 100 cm thick and is composed of interbedded sand, pebbly-sand, coarse sand, granule gravel and diamicton. Individual beds are thin (~5 cm), well to poorly sorted, normally graded, and contain irregularly shaped sand lenses. Sand layers are commonly deformed beneath clasts.

Above a sharp, undulating contact is a 90- to 120-cm-thick, reddish-brown diamicton (Unit 3). The matrix is fine sand to silt, with a 22 percent silt-clay content, and is moderately compact. Clasts are generally angular to sub-angular, and mostly of local provenance, including sediments, metasediments, and tuffs (Gander River complex). Fine-grained, pink, granites probably derived from the Mount Peyton intrusive suite are also found. Striated clasts are common. The clast content is about 50 percent, and clasts are granule gravel to boulder sized. Two clast fabrics were taken from this unit with a 5-m lateral displacement. They showed a strong fabric (S1=0.69, K=2.3), oriented 197 to 017°, parallel to local striae, and a moderately strong fabric with a girdle distribution (S1=0.58, K=0.41), oriented 134 to 314°. Concentrations of vertical clasts were noted within this unit.

The surface sediment (Unit 4) is a 50- to 80-cm-thick, coarse-grained, clast-rich diamicton. The unit is poorly compacted with 60 to 80 percent angular to sub-angular clasts having common leucogranites, similar to those exposed around Gillinghams Pond. Clasts from the Mount Peyton intrusive suite, which are common in the lower sediment, are absent. Striations were absent on clasts. The matrix is fine sand, having less than 10 percent silt and clay.

This exposure contains 3 diamicton units and a subglacial fluvial deposit. Unit 1 is probably a subglacial meltout till (Figure 6). The moderately oriented clast fabrics, sub-rounded, striated clasts and numerous lenses, especially beneath clasts, are consistent with this interpretation (Dreimanis, 1988; Shaw, 1982). Similarly, moderately strong but girdle clast fabrics may reflect reduction of inclination of clasts as a result of melting ice during deposition (Dreimanis, 1988). The low compaction is likely a function of the sandy matrix. The texture, structure and vertical and lateral variability of the underlying sand and gravel unit are consistent with deposition in a fluvial environment. The deformation of sand beds by clasts, the interbeds of diamicton and the overlying diamicton having sharp basal contacts, suggest deposition at the base of a glacier. Subglacial drainage may occur as sheet flow, through microchannels within diamicton (forming sorted sand and granule gravel lenses), or as larger channels cut into the ice or bedrock. Sediments within these channels are similar to their proglacial counterparts (Drewry, 1986). The undulating contact with the underlying diamicton and the deformation of sand beds beneath clasts suggest these sediments were deposited englacially within a channel cut into the ice ('Rothlisberger channel'; Rothlisberger, 1972), and draped over the underlying diamicton. Unit 3 is probably a subglacial melt-out till. The reddish-brown matrix and moderate compaction is similar to diamictons described in the west part of the area. It differs from the lowest diamicton in colour, grain size, compaction and clast provenance. The first three differences reflect the finer sediment matrix, and the clast provenance suggests a local origin. The fabrics, clast shape and striated clasts are all consistent with a subglacial melt-out origin. The surface diamicton is a supraglacial melt-out till. The coarse matrix, angular to sub-angular non-striated clasts, low compaction, and stratigraphic position are consistent with this interpretation (Eyles, 1979; Dreimanis, 1988). The presence of clasts derived from the Gillinghams Pond area suggests transportation northward, consistent with regional striae.

A similar stratigraphy is recorded in a pit about 2 km southeast. It exposes the three diamicton units described above, but does not have the intervening sand and gravel unit. The absence of this unit at this site is perhaps further evidence for the sediments' origin within a subglacial channel.

GLACIOFLUVIAL AND GLACIOLACUSTRINE SEDIMENTS

Glaciofluvial sediments are common in valleys across the area (Figure 4). The areally largest deposits are within the Southwest Gander River valley, and within the area of The Outflow into modern Gander River. Thick exposures of sediment are rare, but where found, they have a similar stratigraphy. Two terrace scarps within the Southwest Gander River valley, one 10 m and the other 20 m high and up to 50 m wide, show a basal unit of > 5 m thick of moderate to well-sorted, coarse to medium sand. This unit has interbeds of well-sorted, coarse or medium sand, and has planar tabular crossbedding, with the direction of flow consistent with modern drainage (northward). This unit coarsens upward into a 2- to 4-m- thick sandy pebble gravel. The gravel has a 50 to 80 percent clast content, having sub-rounded to rounded, pebble to cobble clasts, of mixed rock types. The matrix is medium to coarse sand, with a silt-clay content of about 10 percent (Figure 7). Discontinuous beds of moderately sorted sands or granule gravels are common, especially beneath clasts. The beds are irregularly shaped, although roughly horizontal, and are up to 5 cm diameter and 2 cm thick. In abandoned borrow pits in the Hunt's Ponds area, these beds were steeply dipping (40°). The B-soil horizon is commonly cemented (orthic). Sediment similar to the upper sandy gravel is commonly exposed in glaciofluvial terrain across the area, up to 60 m above current river levels. Well-sorted sands and gravels are relatively rare, and apart from the Southwest Gander River valley, were only found in the Careless Brook valley and in the Fifteen Mile Brook valley in an abandoned gravel pit.

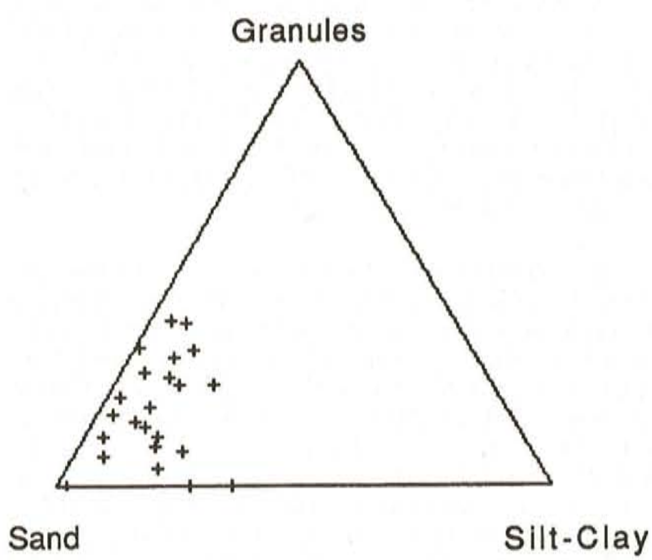

Figure 7. *Ternary plot of glaciofluvial sediments from the Gander map sheet area.*

Poorly sorted sands and gravels are consistent with deposition within glacial meltwater streams, which characteristically have rapid changes in discharge (Sugden and John, 1979). Similarly, steeply dipping beds of the type found at Hunt's Ponds are consistent with deposition in an ice-contact environment (Sugden and John, 1979). However, the presence of thick, well-sorted, crossbedded sands is puzzling, because they are atypical of glaciofluvial outwash environments. It is possible that these sediments reflect deposition within a sandy fluvial system (Walker and Cant, 1984), or deposition within a delta (Miall, 1984).

In the area of The Outflow, glaciofluvial sediments commonly overlie diamictons, up to an elevation of about 60 m a.s.l., or 35 m above the present river level. Glaciofluvial deposits at this elevation were not found elsewhere around the margins of Gander Lake. At Hunts Cove, an outwash terrace associated with flow out of Hunts Brook is 5 m above the present lake level, a similar elevation to deposits at the mouth of Fifteen Mile Brook. Much of the area between modern valleys along the lake exposes either diamictons or colluvium. Boulders along the lake shore are angular and of local provenance. This contrasts with The Outflow area where boulders are commonly rounded and of mixed rock types. This evidence suggests that water levels were higher in the area of The Outflow than elsewhere on Gander Lake.

Further evidence for higher water levels in Gander Lake was found in a backhoe-dug pit near Lukeman Head at an elevation of about 64 m a.s.l. (Figure 8; Plate 2). The stratigraphy showed a basal greenish-grey diamicton unit overlain by a unit composed of interbedded 5- to 15-cm-thick draped silt-clay laminae (Gustavson *et al.*, 1975), and up to 25-cm-thick massive fine sands, capped by a 3-cm-thick massive clay bed. The silt-clay laminae commonly show rhythmic alternation between clay and silt. Clasts are rare, and deform underlying laminae. The contacts between these interbeds are commonly rippled, with a 5 to 20 cm wavelength and a 0.3 to 1.2 cm amplitude. Overlying a sharp contact is a 40-cm-thick, rippled, reverse graded, fine to coarse sand unit. Ripples are sharp crested with a 10 cm wavelength and 2 cm amplitude. The ripples are defined by clay drapes on their upper surfaces. Overlying another sharp contact is a 2.4-m-thick unit of poorly sorted granule gravel, interbedded with well-sorted, planar-bedded granule to pebble gravels. These gravels are well rounded, clast supported, open-work gravels dipping gently southeastward.

This stratigraphy is interpreted as representing four depositional environments. The lower diamicton appears similar to those described earlier and is tentatively assigned a subglacial origin. The overlying unit is interpreted as a lacustrine or glaciolacustrine sediment. The laminated silt-clay, draped laminations, lack of gravel beds and deformation of laminae by clasts that represent dropstones, are consistent with deposition by suspension settling (Ashley, 1988; Gustavson *et al.*, 1975). The rippled sands and draped laminations having rare dropstones overlying the lacustrine sediments suggest deposition by intermittent current flow and suspension settling (Ashley, 1988), probably closer to a sediment inflow area (e.g., a delta) than Unit 2. The overlying coarse, planar-bedded, open-work gravels of the surface unit are interpreted as regressive and transgressive beach deposits (Postma and Nemec, 1990). These beach deposits mark the upper limit of lacustrine activity in the area. The level of beach sediments is similar to the elevation of well-sorted sands described from the Southwest Gander River valley. Therefore, it is possible that these sediments may represent deltaic deposition.

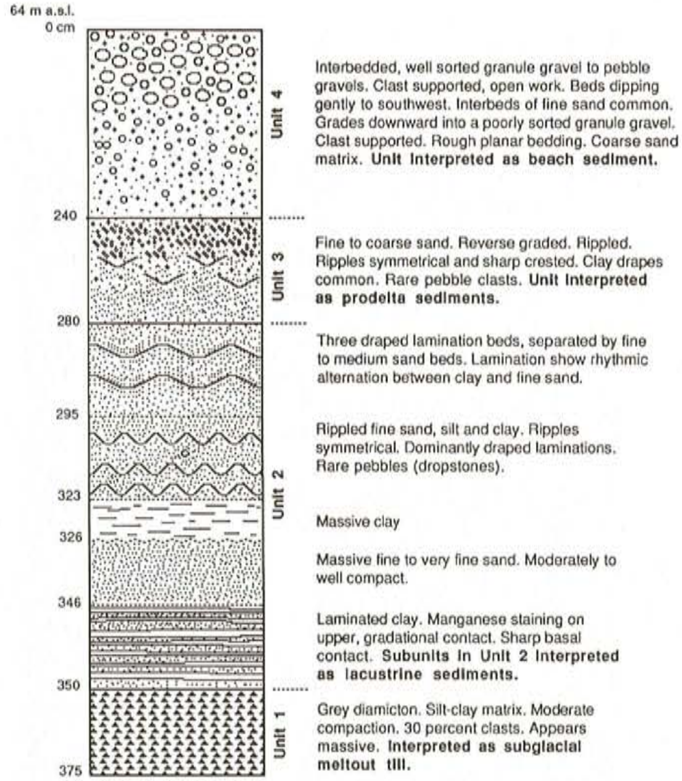

Figure 8. *Stratigraphic column of a backhoe-exposed section in the Lukeman Head area. Not drawn to scale. Refer to text for unit descriptions and to Plate 2 for photograph of section.*

COLLUVIAL SEDIMENTS

On the north shore of Gander Lake, particularly in the vicinity of Gander and on the south shore in the area of Bluff Head, sediments interpreted as colluvium were found. Both these areas lie at the base of steep slopes (Figure 4). Sediment forms 3 to 4 m bluffs in these areas and is composed of a clast-rich diamicton. Matrix is fine sand, having a silt-clay content of 10 to 15 percent, and forms 30 percent or less of the sediment. Clasts are pebble to cobble size, sub-angular to angular, and almost entirely of local origin. The unit is commonly clast supported, with clasts apparently dipping parallel to the slope. On the shore of Gander Lake, about 2 km southeast of Gander at the pumping station, colluvial sediments have incorporated at least 2 organic-rich horizons.

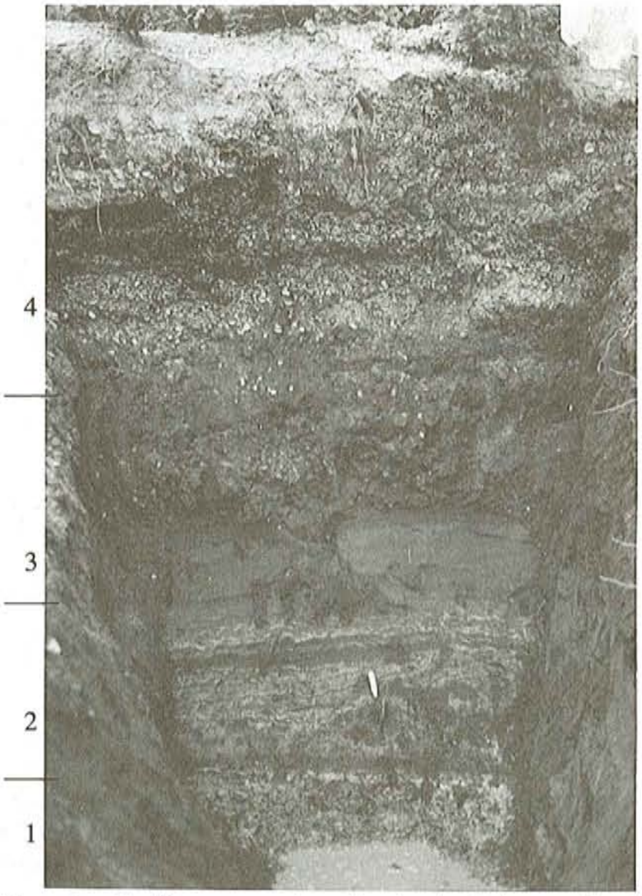

Plate 2. *Backhoe-exposed section in the Lukeman Head area. Trowel for scale. Refer to Figure 8 and the text for details.*

GLACIAL HISTORY–PRELIMINARY OBSERVATIONS

The glacial history of the Gander area is, as yet, poorly understood. The area has been affected by at least two glacial-flow events. The first was from a source to the west, and is consistent with regional ice-flow patterns described by St. Croix and Taylor (1990, this volume). This flow event transported sediment up to 25 km, although most material was probably transported less than 2 km. This eastward-moving ice flow was parallel to Gander Lake, at least in its western part, and suggests that the lake has been modified or formed by glacial action. The depth of the lake, the sediment-filled eastern outlet valley that leads to Freshwater Bay, and its orientation with regards to paleo ice-flow directions led Murray (1882) and Jenness (1960) to speculate that the lake is a fjord. It can be further speculated that Gander Lake was open to the sea at the onset of the last glacial period. No marine sediments were found to support this suggestion, although it is likely that these would lie below the current water level of the lake. The most recent flow direction, as shown by striae, clast provenance and fabrics, was generally north-northeastward, transverse to the lake. It is likely the Gander Lake valley was ice filled at this time.

As deglaciation proceeded, ice retreated toward the higher land to the south of the lake. Many of the glacial meltwater channels in this area were probably cut at this time. The valleys of the Northwest and Southwest Gander rivers acted as major conduits of meltwater drainage, containing streams that deposited sediments up to 60 m above the current river levels. Smaller valleys such as Careless Brook, Joe Batts Brook, and Salmon River also carried glacial meltwater. In the area of The Outflow, higher water levels are shown by waterlain sediments near Lukeman Head, and the possible existence of deltaic deposits in the Southwest Gander River valley. The lack of these deposits to the east of Kings Point suggests that higher water levels did not extend to this area, possibly because the lake was ice filled at this time. However, it is also possible that higher water levels were the result of marine incursion. Raised marine features on the coast have not been examined in detail, but Grant (1980) reports Late Wisconsinan marine limits near Musgrave Harbour on the north coast at 43 m a.s.l. Marine limit at the coast at the eastern end of the lake has been reported at about 30 m a.s.l. (Jenness, 1960; Grant, 1980), although it is difficult to explain the presence of ice-contact sands and gravels, and eskers in the outlet valley at the eastern end of the lake if filled by marine water. Higher water levels drained through the modern Gander River valley. Remnant ice in Gander Lake stagnated, as did ice to the south of the lake. The Hunt's Brook and Fifteen Mile Brook valleys were meltwater conduits at this time.

During the Holocene, organic deposits developed in the poorer drained areas, and colluvial deposits formed at the base of the steeper slopes. Both these processes continue today, although vegetated slopes have retarded the rate of colluviation.

IMPLICATIONS FOR MINERAL EXPLORATION

Despite common erratics identified as originating from the Mount Peyton area to the west, transported by eastward-flowing ice, evidence from striations and from clast fabrics suggests that the last sediment-moving ice-flow event was north to north-northeastward. Most diamictons in the area have been interpreted as basal melt-out tills. The sediment comprising basal melt-out tills are, in general, farther transported than a lodgement till (Dreimanis, 1988), but the clasts suggest that it is representative of the local bedrock, and is, therefore, a suitable sampling medium. However, surface clast-rich diamictons should be avoided. These have been interpreted as supraglacial sediments, which are largely composed of far-travelled sediment. Glaciofluvial sediments should be avoided in any routine sampling program, as the sediment is derived through a fluvial transport system that may carry material long distances from its source. Colluvial sediments should not be sampled in association with diamicton samples, because of the differing transport histories. Colluvium is derived through slope processes, and therefore, samples will be reflective of the up-slope, rather than up-ice direction.

Overall, the glacial history of the Gander area is complex. Mineral-exploration activity in drift-covered areas should identify the genetic environment of samples to examine their suitability to drift-exploration programs. Failure to do so may result in erroneous conclusions regarding the potential source of geochemical or float anomalies in the surficial environment.

IMPLICATIONS FOR LAND-USE PLANNING

In the Gander area, the results of the surficial mapping suggest that the siting of waste-disposal sites (in any surficial sediment) within the drainage basin used for town water-supplies is not recommended. All surficial sediments have a sandy matrix, having numerous sorted lenses that would enhance percolation of pollutants into the groundwater system. The siting of waste-disposal sites on glaciofluvial sediment would also be potentially unsafe for similar reasons. The presence of colluvial deposits at the base of many steeper slopes suggests they are unstable, and therefore, should be avoided as sites for any construction activity. Surficial mapping also points to several new areas of aggregate-resource potential, in particular in the Fifteen Mile Brook area. The suitable zonation of these resources to allow their exploitation, along with those reported by Ricketts and McGrath (1990), are also important to the efficient development of this area.

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